DTU Library

Enhancement of Fracture Resistance by Multiple Cracks in Layered Structures under Mode I and Mix Mode Loading

Goutianos, Stergios; Sørensen, Bent F.

Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Enhancement of Fracture Resistance by Multiple Cracks in Layered Structures under Mode I and Mix Mode Loading

Stergios Goutianos and Bent F. Sørensen*
Department of Wind Energy, Section of Composites and Materials Mechanics, Technical University of Denmark, Risø Campus, DK-4000 Roskilde, Denmark

Layered structures are susceptible to delamination because they often exhibit low interlaminar fracture resistance. Through-thickness stresses e.g. due to manufacturing defects or geometric discontinuities, can result in growing interlaminar cracks which may lead to loss of structural integrity [1]. As a result, a number of techniques have been developed to improve the through-thickness fracture resistance of layered structures e.g. fibre reinforced composites. In the field of composite materials, two directions to develop damage tolerant composites can be identified: a) material improvements (e.g. tougher matrices and interleaves) and b) modifications of the fibre architecture (e.g. stitching, z-pinning, knitting and braiding). These techniques aim to increase the fracture resistance by making the damage prone areas stronger.

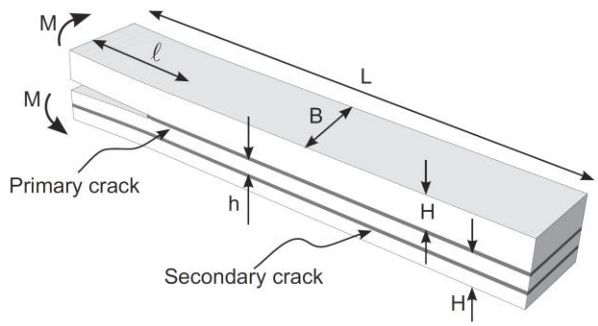

Fig. 1: Double Cantilever Beam specimen loaded with pure bending moments. A secondary crack (weak plane) is introduced to the primary crack at a distance h.

In the present work, a third approach is explored. It is shown, through cohesive zone modelling, that the fracture resistance can be improved by introducing weak layers that result in multiple delaminations next to the damage prone areas. Our model is motivated by the experimental results of Rask and Sørensen [2] who observed that by changing the ply thicknesses of composite beams bonded together with a thermoset adhesive, more delamination cracks could be developed next to the main/primary adhesive/laminate crack. An analytical model, based on the J integral, was developed for multiple delaminations [3]. It is shown that the maximum possible increase (upper limit) of the steady-state fracture resistance, $J_{R,ss}$, scales linearly with the number of delaminations in agreement with the observations of Rask and Sørensen [2]:

$$J_{R,ss} = J^1_{ss} + \eta\, J^2_{ss} \qquad (1)$$

In Eq. 1, J^1_{ss} is the steady-state fracture resistance of the main crack, η is the number of weak planes introduced having a fracture resistance $J^2_{ss.}$ Eq. 1 assumes that secondary weak planes grow in the same direction as the main crack. If the secondary cracks extend in both directions then the second term of the left hand side vanishes and therefore there is no fracture resistance enhancement (lower limit).

In the present study, a cohesive finite element model is used to examine how the properties of the secondary cracks which controls the fracture resistance enhancement. For simplicity only one weak layer is introduced next to the main/primary crack as shown in Fig. 1. More details are given elsewhere [3].

Fig. 2 shows the predicted steady-state fracture resistance enhancement under Mode I for secondary cracks with different cohesive peak traction with respect to the main crack. It can be seen that when the weak layer is close to the main crack, the numerical predictions approach the upper limit analytical prediction of Eq. 1. The difference is attributed to a small secondary crack growth in the opposite direction of the primary crack growth direction.

A similar enhancement under Mixed Mode is shown in Fig. 2. The distance of the secondary crack to the primary crack is h/H=0.01. It can be seen that the magnitude of the steady-state fracture resistance strongly depends on the mode mixity, defined as nominal phase angle of the stress intensity factors of linear elastic fracture mechanics.

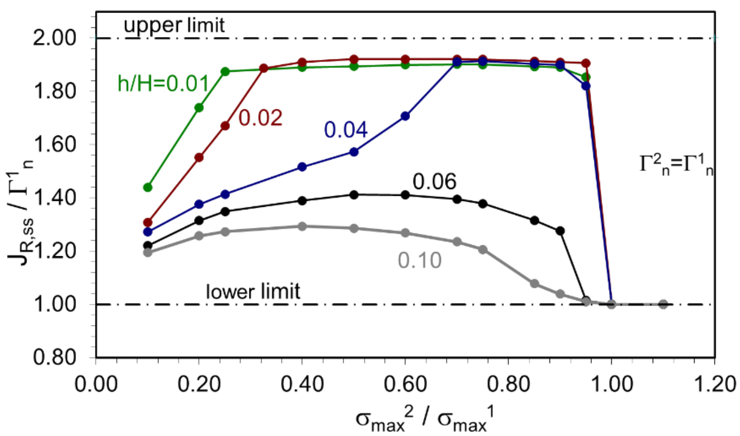

Fig. 2: Steady-state fracture resistance enhancement under Mode I as a function of peak traction of the secondary crack, σ_{max}^2 and the thickness of the layer between the cohesive zones, h. The Mode II cohesive law is equal to the Mode I cohesive law for the primary and secondary crack, respectively. Γ^1_n is the fracture energy of the primary crack.

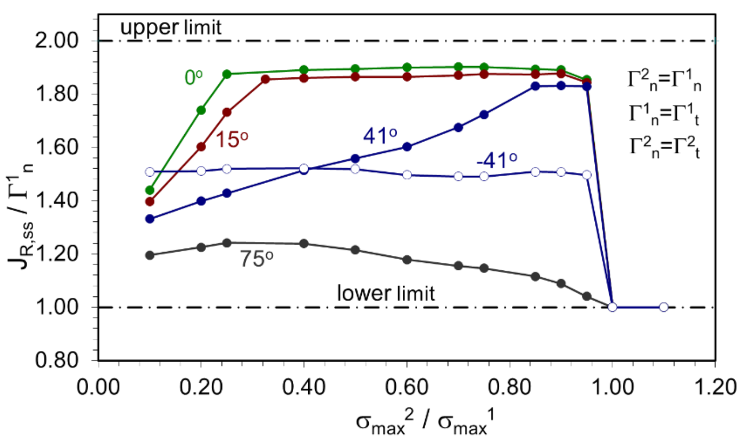

Fig. 3: Steady state fracture resistance enhancement under Mix Mode loading as a function of peak traction of the secondary crack, σ_{max}^2 for h/H=0.01.

Similar results to Figs. 1 and 2 were found for other combinations of cohesive law parameters for the primary and secondary cracks. Thus, it is possible to significantly improve the fracture resistance of a layered structure by adding weak planes.

References:

1. Kim, J. K., Ballie, C., Poh, J., Mai, Y. W. “Fracture toughness of CFRP with modified epoxy matrices”. Composites Science and Technology. 1992, 43, 283–297.
2. Rask, M. and Sørensen, B. F. “Determination of the J integral for laminated double cantilever beam specimens: The curvature approach”. Engineering fracture mechanics, 2012, 96, 37–48.
3. Goutianos, S. and Sørensen, B. F. “Fracture resistance enhancement of layered structures by multiple cracks”. Engineering fracture mechanics, 2016, 151, 92-108.